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Research Article

Predicting the potential distribution of *Ranunculus sardous* (Ranunculaceae), a new alien species in the flora of Uzbekistan and Central Asia

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Abstract

A new alien species in the flora of Uzbekistan, *Ranunculus sardous* Crantz, was identified during a study of plant specimens at the National Herbarium of Uzbekistan (TASH) and in field surveys. *R. sardous* is native to Europe and is reported as an alien species in many other regions, including North America, Australia, China, India, Japan, and Korea. This species was first observed in Uzbekistan in March 2012, with further records in different regions of the country. Field observations confirmed the presence of at least ten populations of this species in the Tashkent and Namangan regions, Uzbekistan. We consider it a locally naturalized alien that might invade both ruderal and segetal plant communities. We modelled the suitability that may drive the future distribution of this new alien species resulting from global climate change based on future climate scenarios and ensemble modelling. The model predicted an overall low suitability for the current climate in Uzbekistan, while suitability would decrease under the Representative Concentration Pathway 8.5 by 2070. The invasive status of *R. sardous* was assessed using its degree of resistance, frequency of occurrence, and ecological-phytocoenotic features. According to the methodology applied, *R. sardous* scored 9 points, which indicates a possible invasion risk to natural flora. Therefore, we suggest prioritising an eradication plan before the species becomes too widespread.

Key words: hairy buttercup, distribution map, species distribution modelling, invasiveness assessment

Introduction

According to the six-volumes of the first edition of "Flora of Uzbekistan" (1941–1962), the native flora of Uzbekistan is composed of 3,663 native species, with many endemic and endangered species, and by 485 non-native species (including species cultivated as crops and ornamentals) (Kudryashev 1941; Vvedensky 1953–1962). The most recent national checklist (*unpublished*) includes more than 4,385 species (Li et al. 2020). The introduction and spread of new alien species are ongoing processes in different regions of Uzbekistan, because of increasing anthropogenic pressure during recent decades. Importantly, several native species of the flora of Uzbekistan (e.g., *Euphorbia esula* L. and *Impatiens parviflora* DC.) are invasive weeds in other countries (CABI 2022).

Currently, the Institute of Botany of the Academy of Sciences of Uzbekistan collects, reviews, and organises data on alien plants. Several studies and surveys have been conducted to assess the taxonomical composition and geographical distribution of the alien flora in Uzbekistan (Mahkamov et al. 2015), and the results have been summarised in the national checklist, listing 228 naturalized and invasive alien species within the framework of the Global Register of Introduced and Invasive Species (GRIIS) project (Sennikov et al. 2020). However, since the publication of this checklist, several new alien species have been recorded. For example, *Anthriscus caucalis* M.Bieb. (Apiaceae), *Chenopodium ficifolium* Sm. (Amaranthaceae), *Cynosurus echinatus* L. (Poaceae), *Euphorbia prostrata* Aiton (Euphorbiaceae), *Galinsoga quadriradiata* Ruiz & Pav. (Asteraceae), *Pistia stratiotes* L. (Araceae), *Rorippa palustris* (L.) Besser (Brassicaceae), *Tragopogon marginifolius* Pavlov (Asteraceae), and *Xanthium albinum* (Widder) Scholz & Sukopp (Asteraceae) were identified as new alien species during the compilation of the checklist of the flora of the Tashkent region as a result of field surveys and revision of specimens stored at the National Herbarium of Uzbekistan (TASH). All these new arrivals are likely to be the result of the increasing international trade, tourism, and transport networks in the last 20–30 years.

In this study, we provide basic information and a detailed description of *Ranunculus sardous* Crantz (hairy buttercup), a new alien species in the flora of Uzbekistan that was found for the first time in Tashkent city in 2012. We also provide photographs of diagnostic morphological traits, distribution patterns and future predictions of invasion risk for Uzbekistan. *Ranunculus sardous* is native to the Canary Islands, North Africa, and from Europe to the West Caucasus (POWO 2022) and has been accidentally introduced in many other regions of the world, including northern European countries such as Sweden (Bengt 2001), Australia (Eichler and Walsh 2007), China (Wang and Gilbert 2001), India (Srivastava 2010), Japan (Fujishima 1990), Korea (Sun et al. 2019), Mexico (Espinosa-García and Villaseñor 2017), and North America (Ferguson et al. 2021). In both its native and invasive ranges, it thrives in disturbed areas, particularly swamp and lowlands, irrigated crops, road verges, farm tracks, and gateways.

Materials and methods

Study area and species

The Republic of Uzbekistan is situated in the southwestern part of Central Asia and occupies an area of 447,400 km^2, of which 425,400 km^2 (95%) is land area. The length of its borders is 6,621 km. The territory of the country is divided into a larger flat north-western area and a smaller submontane and mountain south-eastern part. Deserts and semideserts (including the Kyzylkum Desert and south-eastern part of the Ustyurt Plateau) cover almost 85% of the land in the north-western, northern, and central parts of Uzbekistan. The mountainous land includes the western spurs of the Tian-Shan and Pamir-Alai ranges and their piedmonts and occupies approximately 13% of the territory of Uzbekistan in its eastern and south-eastern parts. The highest peak is the mountain Khazret Sultan peak on the Gissar range (4,643 m above sea level). Approximately 2% of the area of the country is occupied by alluvial valleys. Natural landscapes, with different levels of anthropogenic pressure, occupy 82% of the country's territory. Landscapes transformed by humans make up 18% and include arable lands and urban and industrial settlements. Uzbekistan is characterised by a continental, subtropical climate with big seasonal and daily air temperature fluctuations, and long and hot summers (Kuchkarov et al. 2018).

According to the most recent studies, the genus *Ranunculus* L. is represented by 38 species in the flora of Uzbekistan, with one alien species (*R. arvensis* L.) and 22 endemic species to Central Asia, including one national endemic species (*R. vvedenskyi* Ovcz.) (Ovchinnikov 1953).

Morphological observations of this new alien species were conducted on living plants and dry specimens in 2020. The photographs in the field were captured with a Canon 750D camera (Tokyo, Japan). Specimens stored at the National Herbarium of Uzbekistan (TASH) were examined. Both current records and suitability models overlapped on the map of the phytogeographic regions of Uzbekistan (Tojibaev et al. 2017).

Species distribution modelling and bioclimatic data

In this study, species occurrence data of *R. sardous* were extracted from two sources: (a) the geographical locations of 9 collecting sites in Uzbekistan, as recorded in the labels of 70 herbarium *exissicata* (Table 1, Figure 1), and (b) the Global Biodiversity Information Facility (GBIF, 29 December 2021, https://doi.org/10.15468/dl.fmwpeg). The global data extracted from the GBIF (42 837 records) using the R package rgbif (Chamberlain et al. 2022) were further processed in R to eliminate duplicate records. After this process, 27 196 occurrence records for *R. sardous* remained for further use in models. Nineteen bioclimatic variables were downloaded from the WorldClim website (2.5-minute resolution, ~ 5 × 5 km), (www.worldclim.org) and used as predictor variables (Fick and Hijmans 2017). The IPCC Representative Concentration Pathway 8.5 scenario (RCP 8.5, maximum emission hypothesis for 2070) was used to predict the future distribution of *R. sardous* (Stocker et al. 2013). Before fitting the species distribution models,

Table 1. Recording date, habitat (or land use), altitude (m a.s.l.), vegetation cover (in %) and geographical coordinates (latitude, longitude – WGS84).

No.	Date	Habitat	Altitude	Vegetation cover	Latitude	Longitude
1	28.09.2014	Riverbank	465	80	69.274680	41.335937
2	17.05.2017	Lawn	442	85	69.237595	41.302763
3	27.05.2017	Riverbank	430	85	69.209400	41.300600
4	05.08.2017	Lawn	440	80	69.236394	41.302709
5	07.07.2019 14.08.2019 13.05.2020 30.10.2020	Bank of irrigation ditch	708	65 60 75 55	69.799350	41.572422
6	28.05.2019	Side of fields	1350	75	69.855053	41.312863
7	14.08.2019	Lawn	708	90	69.768380	41.570393
8	30.06.2019	Along roads	657	65	71.815814	40.326249
9	16.12.2020	Lawn	484	95	69.341216	41.337808

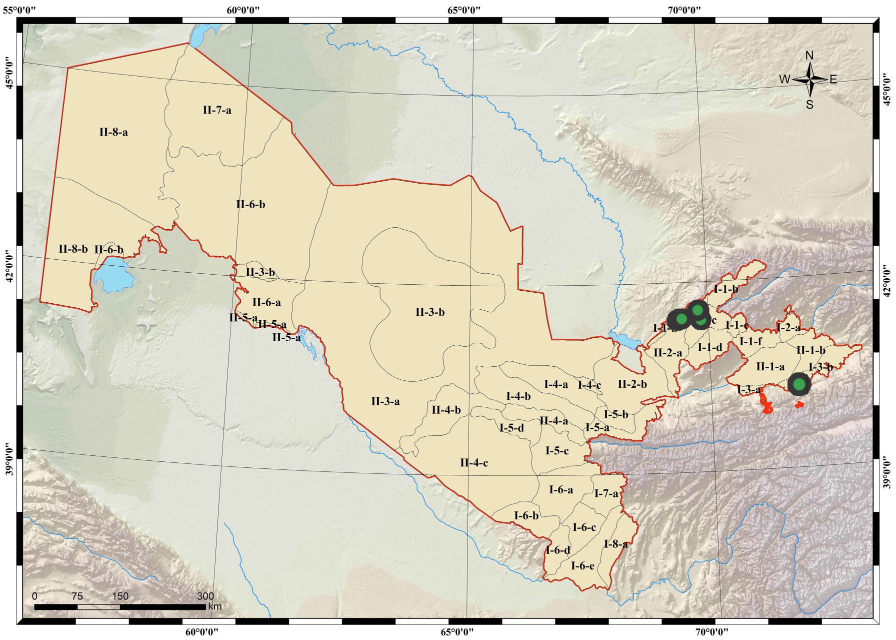

Figure 1. Distribution (ca. 70 records) of *Ranunculus sardous* in eastern Uzbekistan (and supporting herbarium data). **I-1 Western Tien Shan district.** I-1-b Western Chatkal region: CHATKAL RIDGE. Right bank of Parkentsay, between Gulbari and Parkent, 28.05.2019, *Levichev 192* (TASH); vicinity of the Gazalkent, ditch bank, 07.07.2019, *Jabborov 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 463, 464, 465, 466* (TASH); Gazalkent town, inside the lawn, 14.08.2019, *Jabborov, Turdiboev 451, 452, 453, 461* (TASH); vicinity of the Gazalkent, ditch bank, 14.08.2019, *Jabborov, Turdiboev 433, 434, 435, 436, 437, 438, 454, 455, 456, 458, 459, 460, 462* (TASH); vicinity of the Gazalkent, ditch bank, 13.05.2020, *Jabborov, Turdiev 1, 2, 10, 11, 12, 13, 14, 15* (TASH); vicinity of the Gazalkent, ditch bank, 30.10.2020, *Jabborov 1, 2, 3, 4, 5, 6, 7, 8, 9, 10* (TASH). **I-3 Fergana-Alay district.** 1-3-b Eastern Alay region: ALAY RIDGE. Vicinity of Fergana, Damkul village, 30.06.2019, *Turginov, Pulatov, Davidov 467*, *468* (TASH). **II-2 Middle-Sirdarya district.** II-2-a Chinaz region: (Tashkent, left bank of the Ankhor River, 28.09.2014, *Gaziev* Tashkent, "Alley of writers" 24.09.2016, *Gaziev* (TASH); Tashkent, "Alley of writers" 17.05.2017, *Gaziev* (TASH); Tashkent, bank of the Aktepa River, 27.05.2017, *Gaziev* (TASH); Tashkent, Durman yuli str., in the lawn, 16.12.2020, *Jabborov*, *Makhkamov 1, 2, 3, 4* (TASH).

multicollinearity between the environmental variables was assessed using the variance inflation factor (VIF). We used the vifstep function of the usdm package (version 1.1–18) in R (Naimi et al. 2014) to exclude all variables with VIF values greater than 10 and Pearson correlation coefficients ≥ 0.7. The vifstep function calculates the VIF for all variables, excludes the one with the highest VIF (greater than threshold), and repeats the procedure until no variable with a VIF greater than the threshold remains. The seven resulting bioclimatic variables were BIO2, 8, 9, 14, 15, 18, and 19 (mean diurnal range, mean temperature of wettest quarter, mean temperature of driest quarter, precipitation of driest month, precipitation seasonality, precipitation of warmest quarter, and precipitation of coldest quarter, respectively).

This study used an ensemble modelling approach as implemented in the sdm package (Naimi and Araujo 2016) in R software to predict suitable habitats for *R. sardous*. The ensemble modelling approach was selected because it improves the robustness of predictions compared to predictions using single models (Araújo and New, 2007). In the present study, six commonly used algorithms in the area of invasive SDM that were available in the sdm package were used, i.e., generalised linear models (GLMs), support vector machine (SVM), random forests (RFs), boosted regression trees (BRTs), multivariate adaptive regression spline (MARS), and maximum entropy (MaxEnt). For model calibration and validation, the species occurrence points were randomly divided into 75% data for model training and 25% data for model testing. Background samples (pseudoabsences) were randomly generated in R software based on environmental variables for model use (Rathore et al. 2019). Subsequently, models were computed with ten replications for each model to attain a robust estimation of the model performance. In the bootstrapping technique, sampling with replacement is repeated, each time a sample with equal size as the original data is drawn and used for training data. To evaluate the performance of the six models, a threshold-independent evaluation index was used (i.e., area under the receiver operating characteristic curve; AUC) and the true skill statistic (TSS). AUC values can range from 0 to 1, with values above 0.5 indicating models that are better than random predictions. Variable importance and response curves, determining the role of predictor variables in explaining the species distribution, were used for interpreting the outputs of the models.

Assessment of the invasive status

One of the most important characteristics of an alien plant species is its status in the so-called introduction-naturalisation-invasion continuum (Richardson and Pyšek 2012). For a general assessment of the invasive status, Notov and Notov (2009) suggested a set of indicators to be assessed within a given study area such, as the degree of stability of the species, its frequency of occurrence, and its ecological and phytocoenotic features. After scoring the indicators, the sum of the scores can be used to obtain an "invasive status" for a given alien plant and to identify the group with the most "active and stable" taxa.

We assessed the degree of stability of *R. sardous* according to the following scale (Notov and Notov 2009): I – the species is transient in the arrival location and quickly disappears or persists due to its lifespan; sexual reproduction and vegetative spread are not observed (1 point); II – the species is transient in the place of invasion and persists for some time due to its lifespan and/or by vegetative growth; reproduction by seeds is not observed (2 points); III – the species is fully established at the site of arrival due to sexual or vegetative reproduction but does not spread beyond the invaded habitat (3 points); or IV – the species is fully established and actively spreads, with highly effective sexual and/or vegetative reproduction (4 points).

The frequency of occurrence was scored according to the following scale (Bulany 2010): single – a was species recorded in Uzbekistan once (considering collections from 45–50 years ago to modern collections), without considering the number or population density (1 point); very rare – a species is known in 2–5 localities, and it is represented by a single specimen or by one or several populations of up to 100 individuals (2 points); rare – a species for which 6 to 10 localities are known (3 points); occasional – a species for which 10 or more locations are known (4 points); frequent – a species occurring in many communities and habitats, represented by a large number of populations, but not dominant in communities (5 points); common (very–common) – a species with a wide ecological amplitude, included in the majority of plant groups of one formation, often in the role of a codominant, and almost ubiquitous, with a large number of populations (6 points).

The ecological and phytocoenotic features of *R. sardous* were assessed according to the following scale (Pismarkina and Silaeva 2018): E1 – the assessed plant grows only in urbanized (in a broad sense, and not only within cities) biotopes (the geotope has been transformed or destroyed) or on constantly disturbed substrates in natural habitats (1 point); E2 – more widespread in urbanized biotopes (including meadows and steppes disturbed by constant grazing) than in natural biotopes (2 points); E3 – it grows equally both in natural and urbanized biotopes (3 points).

Results

Morphological description

Ranunculus sardous Crantz, Stirp. Austr. Fasc. 84. (1763), is allied to *R. scleratus* L., but it differs in having longer petioles of basal leaves, with the middle segments of the leaves abruptly contracted into a stalk. *Ranunculus sardous* is an annual or biennial herb, 7–45 cm high, pubescent; root-stock corm-like, roots in clusters, not fleshy; stem branched, ribbed (Figure 2).

Radical leaves with long petiole, 3–partite; middle lobe abruptly contracted into a stalk, all variously dentate and lobed, sparsely to densely hairy on both

Figure 2. Main morphological diagnostic traits of *Ranunculus sardous* Crantz in Uzbekistan. A – bud and flower, B – basal leaves, C – general view of the plant, D – stem, E – achenes. Photographs by A. Gaziev.

surfaces; petioles 4–12 cm long; lower cauline leaves smaller, resembling radical leaves; upper cauline leaves sessile with linear lanceolate lobes, 1.2–2.8 cm long, midrib deeply veined, nearly glabrous or faint long hairs. Flowers 1.2–2.5 cm in diam. Sepals 4–5 mm long, broad ovate to ovate – lanceolate, margins membranous with appressed white hairs. Petals pale yellow, 6–8 × 3–4 mm. Achenes 3–5 mm long, minutely punctate with small obtuse tubercles near the margins or sometimes smooth; beak 0.6–0.8 mm long, curved upwards. It flowers and sets fruit in May–October (in some cases, November–December).

Key for the identification of three look-alike Ranunculus *species in Uzbekistan*

1. Herbs annual or biennial 2
2. Achenes emarginate, smooth, not tubercled or spinous, in cylindrical heads .... *R. sceleratus*
2. Achenes marginate, smooth, tubercled or spinous in globose heads 3
3. Achenes tubercled or hooked along only the border or sometimes smooth 4
4. Radical leaves simple, glabrous .... *R. arvensis*
4. Radical leaves 3-partite, sparsely to densely hairy .... *R. sardous*

Distribution of R. sardous *in Uzbekistan*

The occurrences of *R. sardous* in East Uzbekistan are plotted in Figure 1. An analysis of the existing herbarium specimens showed that *R. sardous* was first collected in Uzbekistan in 2014. Other herbarium materials were collected in 2016–2020, while the range of the species has continued to

Table 2. Performance evaluation of SDM methods using different statistical parameters.

Methods	Correlation	AUC	TSS	Kappa	Sensitivity	Specificity	Threshold
GLM	0.89	0.98	0.87	0.87	0.94	0.94	0.61
SVM	0.95	0.99	0.94	0.94	0.97	0.97	0.68
RF	0.98	1.00	0.97	0.97	0.98	0.98	0.53
BRT	0.92	0.99	0.90	0.90	0.95	0.95	0.39
MARS	0.93	0.99	0.91	0.91	0.96	0.96	0.58
MaxEnt	0.93	0.99	0.91	0.91	0.96	0.96	0.40
Ensemble	0.95	0.99	0.94	0.94	0.97	0.96	0.46

expand. However, the date of introduction of this species into the territory of Uzbekistan is likely to be earlier, as supported by a photograph taken by A. Gaziev in 2012 in Tashkent. Moreover, there are still cases where *R. sardous* propagules (fruit/seeds) are being introduced as a contaminant of lawn seeds. For example, *R. sardous* was observed (December 2020) in a lawn planted in 2019, with seeds purchased from an unknown foreign country. Once introduced in a new site, *R. sardous* can be spread by several accidental pathways, including migratory ducks (Brochet et al. 2009).

From the above information, it can be concluded that this alien plant is found in Uzbekistan in many types of disturbed habitats, especially in hydromorphic sites. It also occurs in protected areas in Ugam-Chatkal National Park and occasionally invades natural plant communities.

Ranunculus sardous is adapted to both ruderal and segetal communities, and the number of plants ranges from 70–100 per 100 m^2, where stable populations are formed with sexual and vegetative reproduction. In those communities, *R. sardous* was observed growing with *R. arvensis* long since it naturalized in Uzbekistan. This alien species goes through all stages of ontogenesis. In December 2020, we found plants in the generative phase (G_2). A decrease in temperature and heavy snowfall in early November followed by a rise in temperature in late November–early December may have led to the rapid stratification and germination of plant seeds. The size of a plant in December is almost 2 times smaller than that in April–August.

Model performance and variable contributions under present and future climatic conditions

The performances of SDMs using different evaluation techniques are presented in Table 2. The accuracy of the models was very high. Model accuracy can also be evaluated using the receiver operator characteristics (ROC) curve as it has the capacity to show the proportion of the true presence rate (sensitivity) and the true absence rate (specificity). The ROC curve for all models is presented in Figure 3. Sensitivity and specificity scores were very high for all models indicating both invaded and uninvaded areas were well classed, and the proportion of correctly classified samples was maximum.

The ensemble model was used to produce maps showing the invasion suitability or *R. sardous* both in the current climate and under a future climate

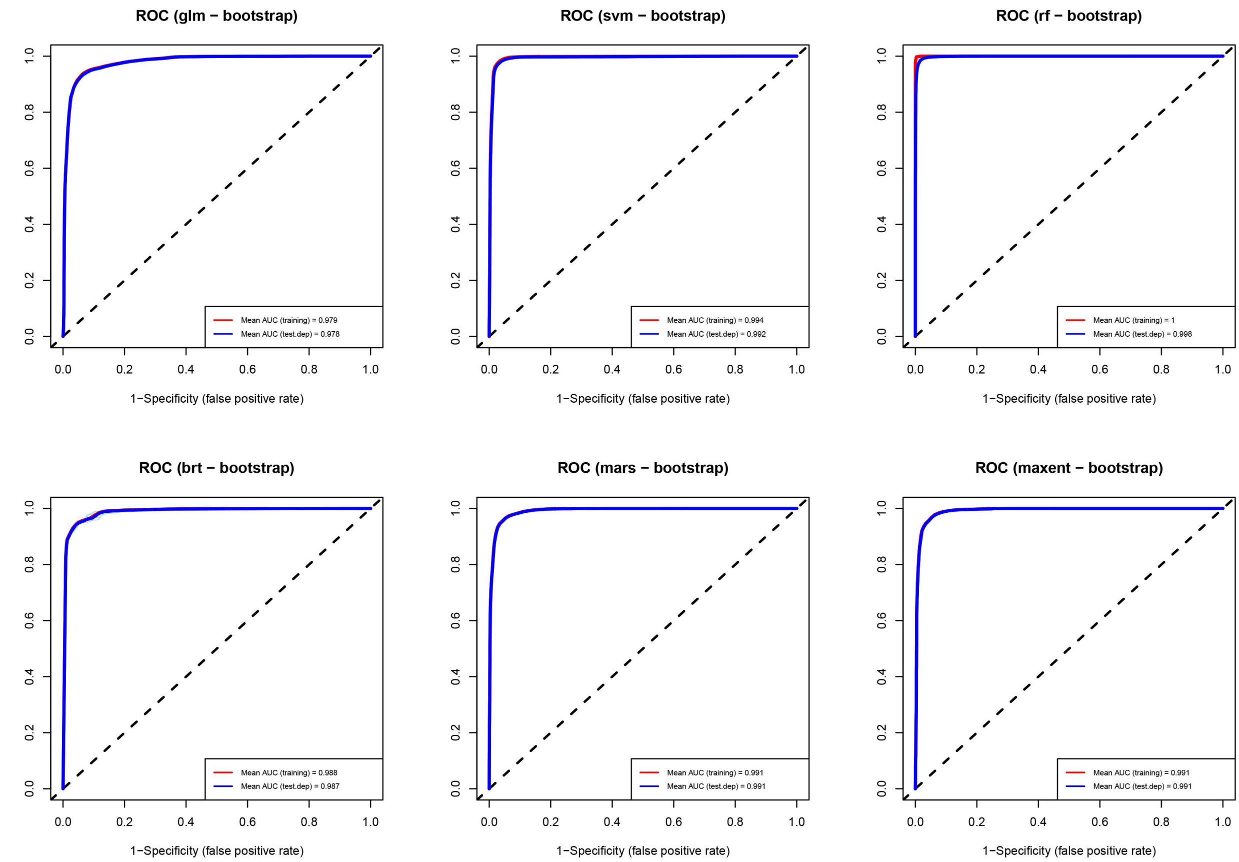

Figure 3. Receiver operator characteristic (ROC) curves using the bootstrap replication method for the six different SDMs applied to *Ranunculus sardous*. Sensitivity (true-positive rate) of the vertical line and 1-specificity (false-positive rate) of the horizontal line describe the proportion of correctly and incorrectly classified samples. The red and blue curves represent the mean AUC using training and test data, respectively.

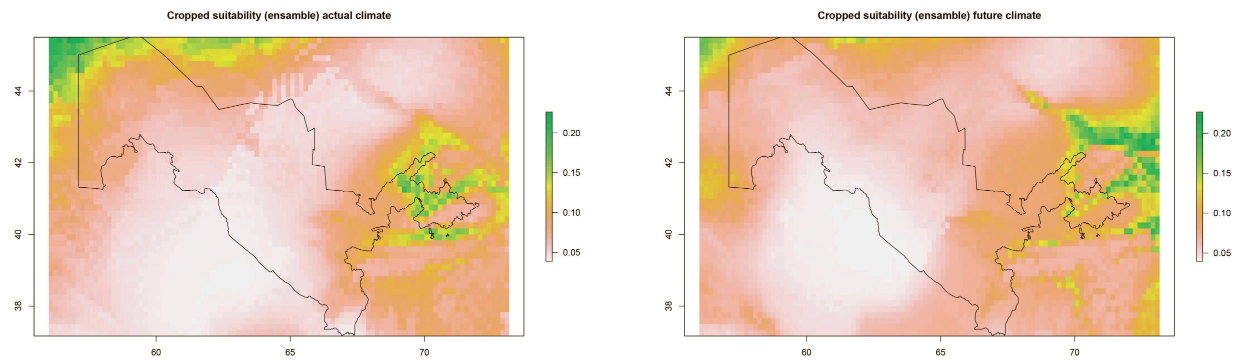

Figure 4. The current and future potential suitability for *Ranunculus sardous* by 2070 according to the RCP 8.5 climate scenario. Dark green areas are more climatically suitable, although all values are under the threshold of 0.46.

change scenario (Figure 4). In the current climate, the suitable regions are in the north-western and north-eastern parts of Uzbekistan. Climate change scenario RCP8.5 2070 showed a reduction in areas with suitable climatic conditions (Figure 4). The relative influence of predictors, and response curves are shown in Figure 5.

Assessment of the invasive status of R. sardous

According to the degree of resistance, *R. sardous* scored 3, i.e., it is fully established in the places of invasion due to sexual or vegetative reproduction,

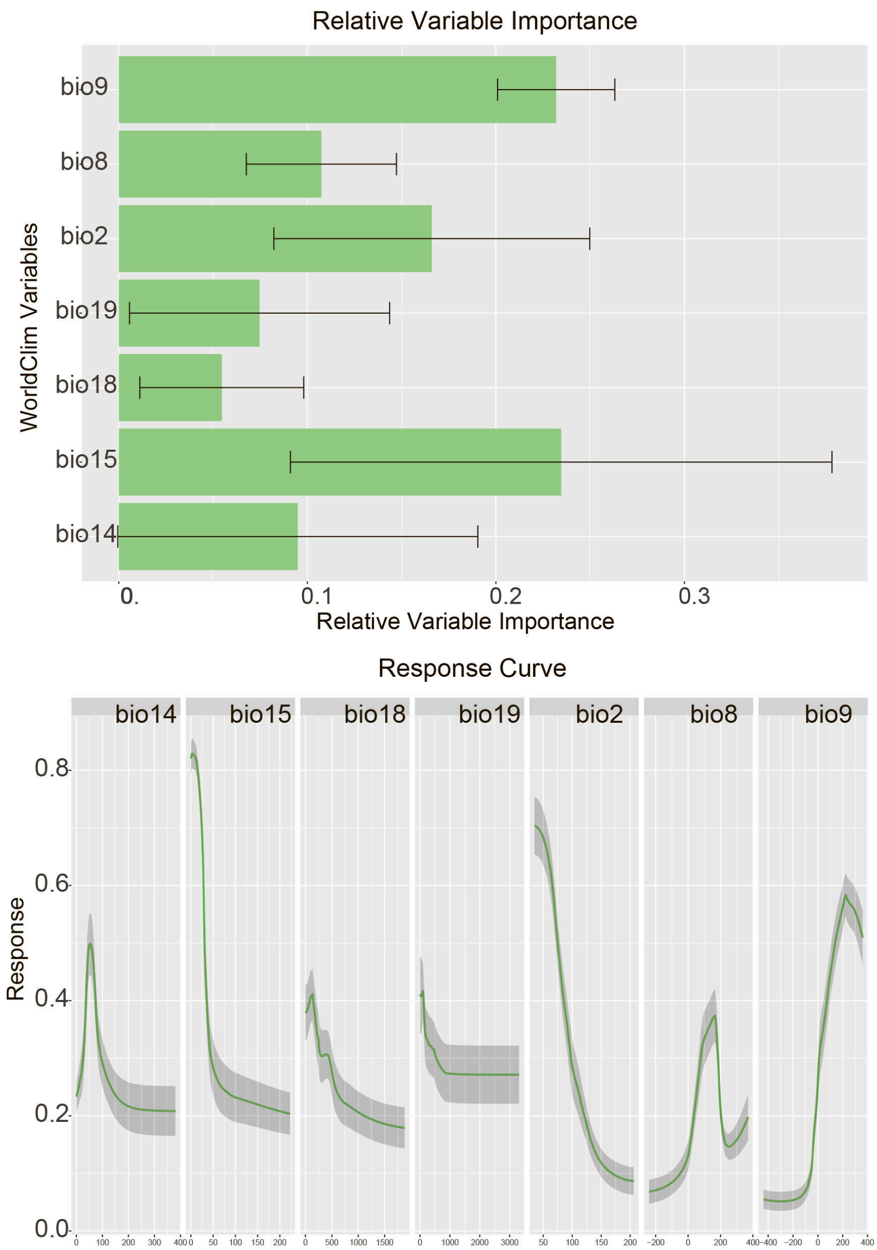

Figure 5. The relative influence of predictive variables for the six different models and response curves for each predictor used in the models. The bioclimatic variables are coded as follows: BIO14 = precipitation of driest month, BIO15 = precipitation seasonality (coefficient of variation), BIO18 = precipitation of warmest quarter, BIO19 = precipitation of coldest quarter, BIO2 = mean diurnal range (mean of monthly (max temp–min temp)), BIO8 = mean temperature of wettest quarter, and BIO9 = mean temperature of driest quarter.

but it does not spread beyond the invaded area. The species scored 4 in terms of frequency of occurrence (i.e., occasional – a species for which 10 or more locations are known). Furthermore, *R. sardous* was assigned to the E2 group and scored 2 points for ecological-phytocoenotic features.

Thus, the invasive status of *R. sardous* in Uzbekistan scored a total of 9 points (for the 3 indicators), i.e., it is an alien plant invading mainly transformed biotopes, where its established populations reproduce sexually and vegetatively, hardly spreading beyond the boundaries of the primary invasion area.

Discussion

The present research is a first attempt to describe the invasive status of *R. sardous* in Uzbekistan according to the methodology proposed by Pismarkina and Silaeva (2018) and to predict its invasion risk with ensemble habitat modelling using occurrences and bioclimatic predictor variables at the geographical scale of the whole country.

There are many different methods used to assess the invasive status of an alien plant and its negative impacts, such as the EICAT methodology (Hawkins et al. 2015; Kumschick et al. 2020). However, like many other methods, the EICAT process relies on published evidence of impacts of the alien taxa under assessment. In fact, its first step is a thorough and exhaustive literature search to identify all published (including grey) literature on the impacts of the alien taxon. This might be a serious hindrance when there is practically no available literature on impacts, as in the case of *R. sardous* in Uzbekistan and in its global range. In the lack of available literature, a methodology based more on expert opinion and field observations, such as the Pismarkina and Silaeva (2018) methodology, may prove to be very useful. A similar expert-based approach was also used for hairy buttercup in Korea by Sun et al. (2019).

Outside the study area, hairy buttercup has been described as a "problematic" weed for winter wheat growers in the southern Great Plains and in the mid-southern United States in recent years (Ferguson et al. 2021), e.g., in pastures in the south-eastern US (Enloe et al. 2014) and in New Zealand (Harrington et al. 2008). However, there is very little information available on invasiveness and impacts, and in a recent search on Web of Science (27 July 2022), only 23 scientific papers for *R. sardous* were found. Hairy buttercup contains ranunculin (Hill and van Heyningen 1951; Neag et al. 2018), which is a precursor to the toxin protoanemonin, which may cause gastrointestinal irritation, but historically, livestock poisonings have rarely been an economic issue associated with *Ranunculus* species in the US (Enloe et al. 2014). In addition, several options for chemical control have been tested and are suggested as effective for use for pastures, agricultural areas, and crops (e.g., Eerens and Mellsop 2008; Enloe et al. 2014; Ferguson et al. 2021), so this alien species could be managed with standard techniques in agricultural areas. In its native range, *R. sardous* can also be found as a weed of arable crops. However, dramatic changes in the composition and richness of arable weed communities have followed changes in crop husbandry since the 1950s and are now well documented in Europe (e.g., Fried et al. 2012) so that hairy buttercup is now considered an endangered segetal weed in part of its native range, like *R. arvensis* (Fanfarillo et al. 2020).

The results of the assessment for *R. sardous* in Uzbekistan, performed using the methodology by Pismarkina and Silaeva (2018), were in line with the global status of hairy buttercup in its invaded range. In fact, *R. sardous* in Uzbekistan invades mainly transformed biotopes, where its established populations reproduce sexually and vegetatively, but it rarely spreads beyond the boundaries of its primary invasion area. For approximately 10 years, field observations have supported the hypothesis that it is unlikely to become a widespread component of natural plant communities in the current situation.

The results of the ensemble model showed that in the current climate, the suitable regions are located only in the north-western and north-eastern parts of Uzbekistan. The two predictive variables with the highest relative influence for the six different models and response curves were BIO9 (mean temperature of driest quarter) and BIO15 (precipitation seasonality, coefficient of variation). These results are consistent with the ecology of *R. sardous* in its native and invasive ranges (Mony et al. 2010; Lukács et al. 2013). For example, populations of this species were observed growing adjacent to a wetland in Korea (Sun et al. 2019). However, it should be noted that in the more climatically suitable areas, all values of the ensemble model were under the threshold of 0.46. Climate change scenario RCP8.5 2070 showed a contraction of areas with suitable climatic conditions. As such, an increase in the current average annual temperature is expected to have a negative effect on the suitability of *R. sardous*, and its area of distribution in the plains would be reduced, but this increase could lead to the emergence of new suitable areas for the species in the high mountains. These results are comparable with those reported for the UK by Berry et al. (2002). Although a large-scale climatic model may be very useful for a country-level analysis and for prioritising areas for monitoring or eradication efforts, other local factors can promote its establishment and invasiveness at the local scale. Some improvements to increase the explanatory power of distribution models include, e.g., the use of land cover variables and high-resolution thematic layers in addition to pure bioclimatic models (e.g., Santamarina et al. 2019). Similarly, projections of climate change are available only at coarse scales, but agricultural and species distribution models in human-disturbed habitats typically require finer-scale climate data to model climate change impacts (Navarro-Racines et al. 2020).

Overall, *R. sardous* does not currently pose a major threat to biodiversity in Uzbekistan. However, due to its limited range and considering that areas suitable for further expansion do exist in the country, we strongly suggest highly prioritising an eradication campaign to prevent any possible future expansion. In fact, both natural spread and accidental human-mediated spread could promote its arrival and establishment in new sites. Therefore, targeted field surveys should be conducted to promote the early detection of possible new populations of the species in areas where climatic conditions are indicated to be more suitable, and special attention should also be paid to these areas in future studies.

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Authors' contributions

TKM, AMJ and ADG performed field surveys, collected herbarium specimens, and studied plant samples at TASH. GB and TKM modelled the suitability changes based on future climate scenarios. TKM, AMJ and GB drafted the manuscript. GB and TKM revised it. All authors have read the final manuscript version and approved the submitted version.

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